Indian J. Phys. **77B** (5), 553-559 (2003)

AN INTERNATIONAL JOURNAL
IJP

Study of kinetic Alfvén wave in the magnetized dusty plasma-particle aspect analysis

R P Shandilya, P Varma and M S Tiwari*
Department of Physics, Dr H S Gour University, Sagar-470 003, Madhya Pradesh, India
E-mail : tiwarims@yahoo.co.in

Received 30 January 2003, accepted 25 June 2003

Abstract The effect of charged dust grain is examined on the field-aligned current, perpendicular current (with respect to $B_{\parallel}$), dispersion relation and growth rate for the kinetic Alfvén wave with bi-Maxwellian distribution function. It is found that negative charge residing on dust grain, enhances the wave frequency and growth rate , however , the frequency obtained is smaller to that of the wave supported by ions and electrons only. The effect of charge concentration on dust grain is found to increase the perpendicular current and to decrease the parallel current to maintain the current continuity. The dust particle density reduces the wave frequency and the growth rate. The present calculation suggests that the presence of dust particles in auroral region may change the scenario of magnetosphere-ionosphere coupling processes and related phenomena

Keywords Field-aligned current, magnetosphere-ionosphere coupling, kinetic Alfvén wave, auroral acceleration, dusty magnetoplasma

PACS Nos. 52.35 Hr, 52.35 Bj, 52.27 Lw

1. Introduction

Many authors have investigated the role of dust on kinetic Alfvén waves in dusty plasmas with external magnetic fields. Kotsarenko *et al* [1] have studied low frequency kinetic Alfvén waves in a dusty plasma using a fluid analysis, which does not include Landau damping. Das *et al* [2] have considered kinetic Alfvén wave analysis in a plasma with magnetized massive dust grains, and have studied damping due to charge fluctuations. Using a fluid model, Shukla and Rahman,[3] recently investigated shear Alfvén waves and other low frequency electromagnetic waves in non uniform dusty magnetoplasmas. In addition to that low frequency, long wavelength kinetic Alfvén waves in multi-beam dusty plasmas with application to comet and planetary rings have been considered [4]. Recently, effects of dust on Alfvén wave absorption in tokamak edge plasmas has been discussed [5]. In the present paper, we use kinetic approach with particle aspect analysis and investigate the effect of magnetized dusty plasma on kinetic Alfvén wave (KAW) .

Earlier, this approach [6-9] was adopted to investigate the trajectories of charged particles in the electromagnetic field of a kinetic Alfvén wave. Expressions are evaluated for the field-aligned current, the perpendicular current, the dispersion relation and the particle energies. The growth rate of the wave was obtained by an energy conservation method. We have adopted the same model in the present investigation.

In the present paper, however, the situation is different in which the system consists of three components *i.e.* ions, electrons, and dust particles. Here, we study the kinetic Alfvén wave in a dusty plasma, taking into account the charge fluctuation and finite Larmor radius effect of the dust grain.To illustrate these effects, we extend the particle aspect analysis in which the growth rate is calculated which will excite the KAW and in addition to dust grain, a new type of growth mode is predicted from dust charge fluctuation consideration. Wave associated currents and dispersion properties are evaluated for the dusty plasma. This calculation suggests that wave frequency, growth rate, perpendicular current and field-aligned current are affected by the presence of negative charge on dust grain and by the density of dust particles.

2. Basic assumptions

The basic assumptions and methodology are the same as those considered by Baronia and Tiwari [6,7] and Dwivedi *et al* [8,9],

*Corresponding Author

except the inclusion of dust grain dynamics on the kinetic Alfvén waves. Thus

$$E = E_{\perp} + E_{\parallel}, \tag{1}$$

where $E_{\perp} = -\nabla_{\perp}\phi$, $E_{\parallel} = -\nabla_{\parallel}\Psi$

and

$$\phi = \phi_1 \cos(k_{\perp}x + k_{\parallel}z - \omega t),$$

$$\psi = \psi_1 \cos(k_{\perp}x + k_{\parallel}z - \omega t). \tag{2}$$

ϕ_1 and ψ_1 are assumed to be a slowly varying function of time t, and ω is the wave frequency. $k_{\perp}$ and $k_{\parallel}$ define the component of wave vector k across and along the magnetic field B_0. The kinetic Alfvén wave is assumed to originate at $t = 0$ when the resonant particles are undisturbed. We consider a low β, (ratio of plasma pressure to the magnetic pressure) collisionless plasma satisfying the conditions :

$$V_{T\parallel d}, V_{T\parallel i} << \frac{\omega}{k} << V_{T\parallel e}, \omega << \Omega_i, \Omega_e, \Omega_d; k_{\perp}^2\rho_e^2$$

$$<< k_{\perp}^2\rho_i^2, k_{\perp}^2\rho_d^2 < 1, \tag{3}$$

where $V_{T\parallel i}$, $V_{T\parallel e}$ and $V_{T\parallel d}$ are the thermal velocities of ions and electrons along the magnetic field, $\Omega_{i,e,d}$ are gyration frequencies and $\rho_{i,e,d}$ the mean gyro-radii of the respective species. Considering the equation of motion for the charged particles, detailed calculations of particle trajectories in the presence of a kinetic Alfvén wave have been performed by Baronia and Tiwari [6]. The density perturbations $n_1(r,t)$ due to the presence of a kinetic Alfvén wave for the resonant and non-resonant particles have also been evaluated .

3. Distribution function

To determine the dispersion relation and the growth rate, we use the bi-Maxwellian plasma with density distribution [7] :

$$N(y, V) = N_{0j}\left|1 - \varepsilon\left(y + \frac{V_x}{\Omega}\right)\right| f_{\perp}(V_{\perp}) f_{\parallel}(V_{\parallel}) \tag{4}$$

where

$$f_{\perp}(V_{\perp}) = \frac{m}{2\pi T_{\perp}} \exp\left(-\frac{mV_{\perp}^2}{2T_{\perp}}\right)$$

$$f_{\parallel}(V_{\parallel}) = \frac{m}{2\pi T_{\parallel}} \exp \frac{mV_{\parallel}^2}{2T_{\parallel}}$$

Here, N_{oj} is the equilibrium density of the j-th species and $T_{\perp}$ and $T_{\parallel}$ are the perpendicular and parallel temperatures with respect to the ambient magnetic field (in energy units) and $\in$ is a small parameter of the order of inverse of the density gradient scale length.

4. Dispersion relation

We use the expression of $n_{1\,i,e,d}$ for non-resonant particles which has been evaluated by Baronia and Tiwari [6] as

$$n_1(\bar{r},t) = N(V)\sum_{-\infty}^{+\infty} J_n(\alpha)\sum_{-\infty}^{+\infty} J_l(\alpha)\frac{q}{m}\left[\left\{\phi_1 - \frac{V_{\parallel}k_{\parallel}}{\omega}(\phi_1 - \psi_1)\right\}\right.$$

$$\left.\left.\frac{k_{\perp}^2}{a_n^2} - \frac{\Omega^2 V_d k_{\perp} m}{\Lambda_n a_n^2 T_{\perp}}\right\} + \frac{k_{\parallel}^2}{\Lambda_n^2}\left\{\psi_1 + \frac{n}{\alpha}\frac{V_{\perp}k_{\perp}}{\omega}(\phi_1 - \psi_1)\right\}\right]\cos\xi_{nl}. \tag{5}$$

$J_n(\alpha)$ and $J_l(\alpha)$ are Bessel's functions which arise from different periodical variations of particle trajectories. The term represented by Bessel's functions shows the reduction of the field intensities due to finite gyro-radius effect. V_d is the diamagnetic drift velocity which is defined by

$$V_d^j = \frac{T_{\perp j}}{m_j\Omega_j}\frac{1}{N}\frac{dN}{dy} \tag{6}$$

and $V_d^i = V_d^d = 0$, represent the homogeneous plasma. q is the charge which is equal to e for ions, $-e$ for electrons and $-Z_d e$ for dust particles.

$$\alpha = \frac{k_{\perp}V_{\perp}}{\Omega},$$

$$\Lambda_n = k_{\parallel}V_{\parallel} - \omega + n\Omega,$$

$$a_n^2 = \Lambda_n^2 - \Omega^2,$$

$$\xi_{nl} = k_{\perp}x + k_{\parallel}z - \omega t + (l-n)(\theta - \Omega t).$$

θ is the initial phase of the velocity and $\Omega = qB_0 / mc$. The slowly varying quantities ϕ_1 and ψ_1 are treated as a constants.

With the help of distribution function (eq.(4) and eq.(5)), we find the average densities for inhomogeneous plasma as [6,7]

$$n_i = -\frac{\omega_{pi}}{4\pi e}\left[-\frac{k_{\perp}^2\phi}{\Omega_i^2} + \frac{k_{\parallel}^2\psi}{\omega^2} + \frac{V_d^i k_{\perp} m_i\phi}{T_{\perp i}\omega}\right]\left(1 - \frac{1}{2}k_{\perp}^2\rho_i^2\right), \tag{7a}$$

$$n_e = \frac{\omega_{pe}}{4\pi e V_{T\parallel e}}\cdot\psi, \tag{7b}$$

$$n_d = -\frac{\omega_{pd}^2}{4\pi Z_d e}\left[-\frac{k_{\perp}^2\phi}{\Omega_n^2} + \frac{k_{\parallel}^2\psi}{\omega^2} + \frac{V_d^d k_{\perp} m_d\phi}{T_{\perp d}\omega}\right.$$

$$\left.\times\left(1 - \frac{1}{2}k_{\perp}^2\rho_d^2\right)\right], \tag{7c}$$

where $\omega_{pj}^2 = \dfrac{4\pi N_{0j} q_j^2}{m_j}$, $j = i, e$ and d.

It is observed that the essential feature of the kinetic Alfvén wave is retained even in this ideal case. We use the dusty plasma quasi-neutrality condition as

$\bar{n}_i = \bar{n}_e + Z_d \bar{n}_d$ (Z_d = charge residing on the dust grain)

to get the relation between ϕ and ψ as

$$\phi = \frac{\Omega_d^2}{k_\perp^2} \frac{\omega_{pi}^2}{\omega_{pd}^2 V_{T\parallel e}^2 Q} - \frac{k_\parallel^2}{\omega^2}\left(1 + \frac{SP}{Q}\right) R^{-1} \psi, \tag{8}$$

where

$$P = 1 - \frac{1}{2} k_\perp^2 \rho_i^2, \; Q = 1 - \frac{1}{2} k_\perp^2 \rho_d^2, \; S = \frac{N_0}{N_{d0}} \frac{m_d}{m_i} \frac{1}{Z_d^2},$$

$$R = \left(1 - \frac{V_d^d \Omega_d^2 m_d}{T_{\perp d} k_\perp \omega}\right) + \frac{SP}{Q}\left(\frac{\Omega_d^2}{\Omega_i^2} - \frac{V_d^i \Omega_d^2 m_i}{T_{\perp i} k_\perp \omega}\right)$$

Using perturbed ion, electron and dust particle densities n_i, n_e and n_d and Ampere's law in the parallel direction [10], we obtain the equation

$$\frac{\partial}{\partial z} \nabla_\perp^2 (\phi - \psi) = \frac{4\pi}{c^2} \frac{\partial}{\partial t} J_z, \tag{9}$$

where

$$J_z = \int_0^\infty 2\pi V_\perp dV_\perp \int_{-\infty}^{\infty} dV_\parallel \Big[\{N(V) u_z(r,t) + V_\parallel n_1(r,t)\}_i$$

$$-\{N(V) u_z(r,t) + V_\parallel n_1(r,t)\}_e - \{N(V) u_z(r,t) + V_\parallel n_1(r,t)\}_d\Big]. \tag{10}$$

J_z is the current density which is contributed by first-order perturbations of density and velocity. With the help of eqs. (4),(5) and expression for u_z as calculated by Baronia and Tiwari [6], we obtain J_z; hence with the help of eqs.(8) and (9), we obtain the dispersion relation for the kinetic Alfvén wave in inhomogeneous dusty plasma as

$$-\frac{\omega^2}{k_\parallel^2 C_d^2 Q}\Bigg)\left(1 - \frac{\omega^2 Q}{V_A^2 k_\parallel^2} R\right) = \frac{k_\perp^2 \omega^2 R}{k_\parallel^2 \Omega_d^2} - \frac{\omega_{pi}^2 \omega_{pe}^2 \omega^2 P}{\omega_{pd}^2 c^2 k_\parallel^2 \Omega_i^2 V_{T\parallel e}^2 Q}$$

$$\frac{T_{\parallel i}}{m_i}\Bigg) + \frac{\omega_{pi}^2 P}{c^2 \Omega_i^2}\left(\frac{T_{\parallel i}}{m_i}\right)\left(1 + \frac{SP}{Q}\right) - \frac{\omega_{pi}^2 \omega^2 P k_\perp^2 R}{c^2 k_\parallel^2 \Omega_i^2 \Omega_d^2}\left(\frac{T_{\parallel i}}{m_i}\right)$$

$$+\frac{\omega_{pi}^2 \omega^2 PR}{c^2 k_\parallel^2 \Omega_d^2} + \frac{\omega_{pi}^2 \omega P}{c^2 k_\parallel^2 \Omega_d^2}\left(\frac{T_{\parallel i}}{m_i}\right)\frac{V_d^i k_\perp m_i}{T_{\perp i}} + \frac{\omega_{pe}^2 \omega^2}{c^2 \Omega_d^2 V_{T\parallel e}^2 k_\parallel^2}\left(\frac{T_{\parallel d}}{m_d}\right.$$

$$-\frac{\omega_{pd}^2 Q}{c^2 \Omega_d^2}\left(\frac{T_{\parallel d}}{m_d}\right) + \frac{\omega_{pd}^2 Q}{c^2 \Omega_d^2}\left(\frac{T_{\parallel d}}{m_d}\right)\frac{k_\perp^2 \omega^2 R}{k_\parallel^2 \Omega_d^2}$$

$$+\frac{\omega_{pd}^2 \omega Q}{c^2 k_\parallel^2 \Omega_d^2}\left(\frac{T_{\parallel d}}{m_d}\right)\frac{V_d^d k_\perp m_d}{T_{\perp d}} R - \frac{SP}{Q}, \tag{11}$$

where $C_d^2 = \dfrac{\omega_{pd}^2 V_{T\parallel e}^2}{\omega_{pe}^2}$ is the square of dust acoustic speed,

$V_A^2 = \dfrac{c^2 \Omega_d^2}{\omega_{pd}^2}$ is the square of dust Alfvén speed.

The dispersion relation of kinetic Alfvén wave reduces to that derived by Baronia and Tiwari [6,7] under the approximation $Z_d = 0$, $V_d^i = V_d^d = 0$, and $I_0(\lambda_{i,d}) e^{-\lambda_{i,d}} \sim 1 - \lambda_{i,d}$ and $\lambda_j = \frac{1}{2} k_\perp^2 \rho_j^2 < 1$ as we have applied and the existence of dust grain is ignored. $I_0(\lambda_j)$ is the modified Bessel function.

5. Current density

The perturbed current per unit wavelength in the presence of KAW with dusty plasma is evaluated by using the following set of equations,

$$J_j = \int_0^\lambda ds \int_0^\infty 2\pi V_\perp dV_\perp \int^{+\infty} dV_\parallel e\big[(N + n_1)(V + u) - NV\big]_{i,e,d}, \tag{12}$$

where

$j = i, e$ and d for respective species,

$$J = J_i - J_e - J_d. \tag{13}$$

With the help of eqs. (4),(5) and expression for $u_x(r,t)$ and $u_z(r,t)$ by Baronia and Tiwari [6,7], we obtain the perpendicular and parallel current as :

$$J_x = \frac{k_\perp k_\parallel^2 e \lambda_1 \psi_1}{8\pi} \frac{\omega_{pe}^2}{m_e \Omega_e^2}\left\{\frac{(\phi_1 - \psi_1)}{\omega} + \frac{2\omega m_e}{k_\parallel^2 2T_{\parallel e}} \psi_1\right.$$

$$\frac{\omega_{pi}^2 \phi_1}{m_i \Omega_i^2 \omega}\left(1 - k_\perp^2 \rho_i^2\right) + \frac{\omega_{pd}^2 Z_d \phi_1}{m_d \Omega_d^2 \omega}\left(1 - k_\perp^2 \rho_d^2\right) \tag{14}$$

and

$$J_z = \frac{e k_\parallel \lambda_1 \psi_1}{8\pi}\left[\frac{\omega_{pe}^2}{m_e}\left\{\frac{k_\perp^2}{\Omega_e^2} \frac{(\phi_1 - \psi_1)}{\omega} + \frac{2\omega m_e}{k_\parallel^2 2T_{\parallel e}} \psi_1 \cdot \frac{8\omega \psi_1}{k_\parallel^2 V_{T\parallel e}^4}\right.\right.$$

$$-\frac{\omega_{pi}^2}{m_i}\left\{\frac{k_\perp^2 \phi_1}{\Omega_i^2 \omega} - \frac{4\psi_1}{k_\parallel V_{T\parallel i}^3}\right\}\left(1 - k_\perp^2 \rho_i^2\right)$$

$$\left.+\frac{\omega_{pd}^2 Z_d}{m_d}\left\{\frac{k_\perp^2 \phi_1}{\Omega_d^2 \omega} - \frac{4\psi_1}{k_\parallel V_{T\parallel d}^3}\right\}\left(1 - k_\perp^2 \rho_d^2\right)\right]. \tag{15}$$

In the evaluation of the current densities, it was assumed that the field-aligned current and perpendicular current are due to an electromagnetic kinetic Alfvén wave and the contribution due to diamagnetic drift was neglected. The average current in first order, vanishes due to periodical variations; however, the average current is contributory in the second order.

6. Energy balance and growth rate

The wave energy density per unit wavelength W_w is the sum of the pure field energy and the change in the energy of non-resonant particles. Following the description of Baronia and Tiwari [6,7], the change in energy of dust particles is evaluated as

$$W_d = \frac{\lambda k_\parallel^2}{16\pi}\frac{\omega_{pd}^2}{\omega^2}\left(1-k_\perp^2\rho_d^2\right)\psi_1^2 - \frac{2k_\perp^2\phi_1\psi_1}{\Omega_d^2}\left(\frac{T_{\parallel d}}{m_d}\right) - \frac{2k_\perp^2\omega\psi_1}{\Omega_d^2}(\phi_1-\psi_1)\left(\frac{T_{\parallel d}}{m_d}\right) + \frac{4k_\perp V_d^d}{\omega}\left(\frac{T_{\parallel d}}{m_d}\right)\psi_1 + \frac{2k_\perp V_d^d}{\omega}(\phi_1-\psi_1)\psi_1\left(\frac{T_{\parallel d}}{T_{\perp d}}\right) - \frac{6k_\parallel^2}{\omega^2}\left(\frac{T_{\parallel e}}{m_d}\right)|\psi_1^2 \tag{16}$$

whereas, the change in energy of resonating electrons is given as [6,7]

$$W_e = \pi^{1/2}\frac{\lambda k_\parallel^2\psi_1^2\omega_{pe}^2}{8\pi}\frac{\omega t}{k_\parallel^2(T_{\parallel e}/m_e)}\times\frac{\left[\omega-k_\perp V_d^e(T_{\parallel e}/T_{\perp e})\right]}{k_\parallel(2T_{\parallel e}/m_e)^{1/2}} \times\exp\left|-\frac{m_e\omega^2}{2T_{\parallel e}k_\parallel^2}\right. \tag{17}$$

Using the law of conservation of energy, we calculate the growth rate of KAW as

$$\frac{\gamma}{\omega} = \pi^{1/2}\frac{\dfrac{\omega}{k_\parallel V_{T\parallel e}}\left[\dfrac{T_{\parallel e}k_\perp V_d^e}{T_{\perp e}\omega}-1\right]\times\exp\left|-\dfrac{\omega^2}{k_\parallel^2 V_{T\parallel e}^2}\right.}{\left[1+\dfrac{\omega_{pi}^2}{\omega^2}\times\dfrac{k_\parallel^2}{\omega_{pe}^2}\times\dfrac{T_{\parallel i}}{m_i}\left(1-k_\perp^2\rho_i^2\right)+\dfrac{\omega_{pd}^2}{\omega^2}\times\dfrac{k_\parallel^2}{\omega_{pe}^2}\times\dfrac{T_{\parallel d}}{m_d}\left(1-k_\perp^2\rho_d^2\right)\right]} \tag{18}$$

where $V_{T\perp,\parallel}^2 = (2T_{\perp,\parallel}/m)$; V_d^e represents electron diamagnetic drift velocity and the value of ω for the drift kinetic Alfvén waves has to be substituted in the expression of growth rate.

It is noted that the kinetic Alfvén wave can be excited only when $(T_{\parallel e}/T_{\perp e})k_\perp V_d^e > \omega$. Thus, the kinetic Alfvén wave is excited as the usual drift wave.

7. Results and discussion

In the present analysis, the expressions for the dispersion relation, current and growth rate are evaluated in the dusty magnetosphere. In this model calculation, we have to examine effect of dust grain on KAW, therefore, chosen the same parameter as considered in earlier work [6,7] The observations of dust grain in auroral acceleration region are rare; therefore, an arbitrary value is selected for the qualitative analysis. The results are presented as Figures 1-4.

$$B_0 = 4300nT,\ \Omega_i = 412s^{-1},\ \Omega_d = \frac{Z_d eB_0}{m_d c} = 6.88\times10^{-10}Z_d,$$

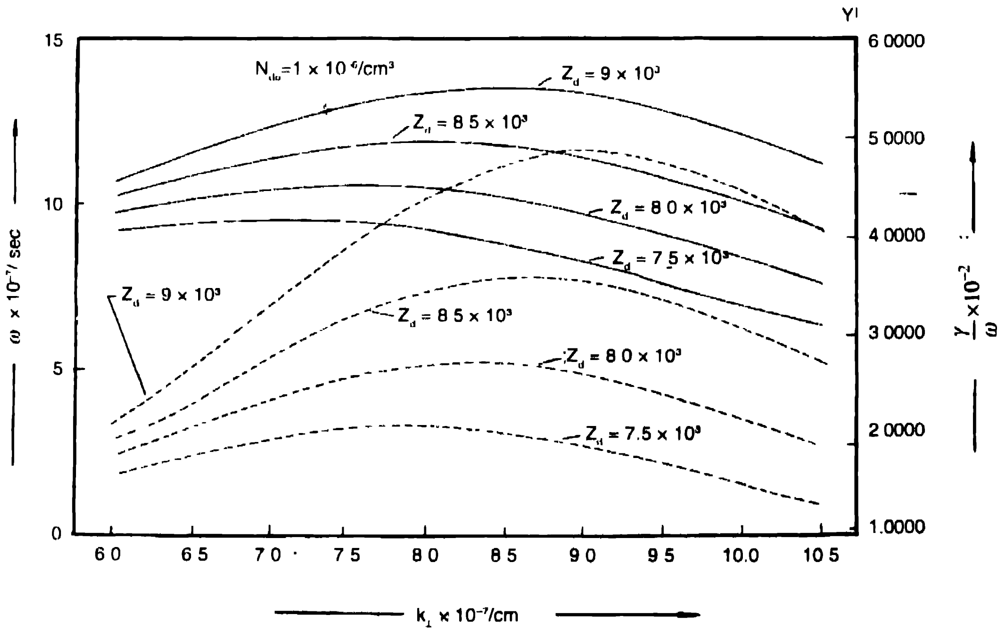

Figure 1. Frequency ω (——) and growth rate $\frac{\gamma}{\omega}$ (-----) *versus* perpendicular wave number $k_\perp$ for different Z_d, $k_\parallel = 10^{-13}$ cm^{-1}

$$N_0 = 10\,\mathrm{cm}^{-3},\ m_d = 10^{-12}\,\mathrm{g},\ \frac{\omega_{pi}}{\Omega_i} = 10,\ kT_{\parallel i} = 100\,\mathrm{eV},$$

$$kT_{\parallel e} = 10\ \mathrm{keV}.$$

Figure 1 shows the variation of wave frequency ω (rad / sec) *versus* perpendicular wave number $k_\perp$ for different values of dust grain charge Z_d at fixed values of equilibrium dust number density N_{d0} . It is observed that negative charge residing on dust grain, enhances the wave frequency at the lower values of $k_\perp$ due to the weakening of wave electric field averaged over the Larmor radius . At lower $k_\perp$, effect is smaller as compared to higher $k_\perp$ .At the higher values of $k_\perp$, the effect of Z_d is to increase the wave frequency. The dust particles containing higher charge are more affected by the electromagnetic field of the wave due to higher force and higher mass, enhance the phase velocity of the wave. The increased phase velocity from the particle velocity, may cause the acceleration of the charged particles by the wave particle interaction mechanism. Because of the fact that lower frequency waves are supported by higher charge and higher mass particles, the frequency obtained is smaller to that supported by ions only. As compared to earlier investigations [6,7] of the KAW, the lower wave frequency waves will be driven by the presence of dust particles.

Figure 1 also shows the variation of growth rate γ / ω *versus* $k_\perp$ for different values of Z_d at fixed N_{d0}. It is found that the negatively charged dust grain contributes to wave growth. It means that the charge concentrations are the source of free energy to excite the kinetic Alfvén wave and to enhance the growth of wave. It means that Alfvénic disturbances are set up at propagate towards ionosphere. The reduction in growth rate at higher wave number may be due to less interaction due to weakend wave electric field averaged over Larmor orbit. Thus, the small fraction of negatively charged dust grain may contribute to the generation of KAW which is the finding of the present investigation.

Figure 2 shows the variation of perpendicular and parallel currents with $k_\perp$ for different values of dust grain charge Z_d at fixed dust number density N_{do} . The figure predicts that current can be generated by the drift kinetic Alfvén wave and constitute a coupled system of perpendicular and parallel currents as well as the potential drop along the auroral field lines in the acceleration region .The wave driven perpendicular current J_x and parallel current J_z are affected due to dust grain charge. It can be seen that the J_x decreases at higher $k_\perp$ due to weakening of perpendicular component of wave electric field because of Larmor radius effect and J_z increases to maintain the current continuity The effect of Z_d is to increase J_x and to decrease J_z to maintain the current continuity. Thus, the presence of dust grain in the lower ionosphere, modifies the current sheet appreciably and the current pattern driven by kinetic Alfvén wave in the auroral ionosphere [6,7] may change due to presence of dust particles. Thus, the direction and magnitude of the field-aligned current may also depend upon the presence of dust particles.

Figure 3 exhibits the variation of wave frequency ω *versus* $k_\perp$ for different equilibrium dust number density N_{d0} at the fixed values of dust grain charge Z_d It is seen that the wave frequency is decreased at the higher wave number due to the increase of density of the particles. Because of the high inertia of the dust particles wave frequency associated with the dust particles is smaller compared to the simple KAW associated with the plasma

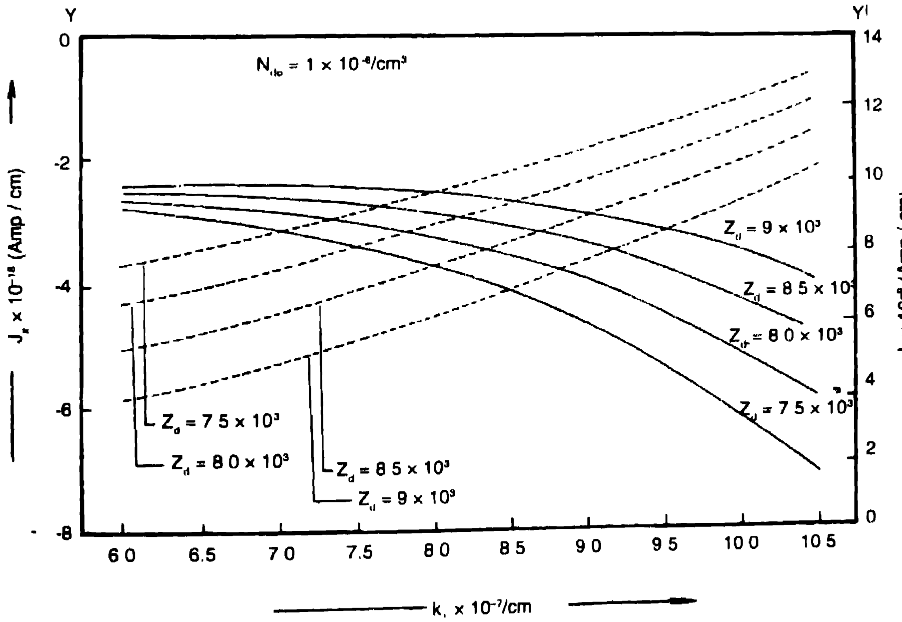

Figure 2. J_x (——) and J_z (-----) *versus* perpendicular wave number $k_\perp$ for different Z_d, $k_\parallel = 10^{-}$ cm^{-1}.

particles without grains. The increase in dust density reduces the wave frequency as higher mass particles support the lower frequency wave. This Figure also predicts the variation of growth rate γ / ω *versus* $k_\perp$ for different values of dust number density N_{d0} at the fixed values of dust grain charge Z_d. Here, it is observed that at the higher values of N_{d0}, the growth rate is reduced due to abundance of the dust particles.

Figure 4 shows the variation of perpendicular and parallel current *versus* $k_\perp$ for different equilibrium dust number density N_{d0} at the fixed values of dust grain charge Z_d. Here, it is noticed that the effect of density of dust particles contributed in perpendicular current variation. At the higher values of number density, the current is increased in the negative x-direction. It is justified that the continuity condition of current is seen by these figures.

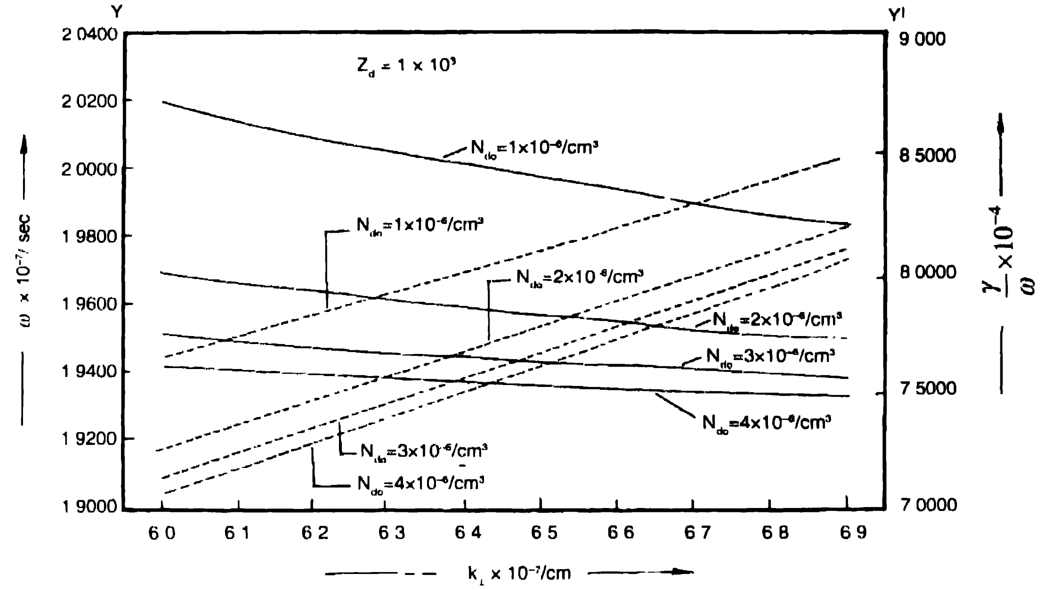

Figure 3. Frequency ω (——) and growth rate γ / ω (-----) *versus* perpendicular wave number $k_\perp$ for different N_{d0}, $k_\parallel = 10^{-13}$ cm^{-1}.

8. Summary and conclusion

In this paper, we have described the various features (frequency, growth rate , field-aligned current) of kinetic Alfvén wave with dusty magnetoplasma. The focus was on the dust effects on kinetic Alfvén wave which is excited only when $(T_\parallel / T_\perp) k_\perp V_d^e > \omega$. Due to lack of observations of the dust grain in the auroral acceleration region, our study is qualitative , and only predicts the effects of the dust grain on the kinetic Alfvén wave model of magnetosphere-ionosphere coupling

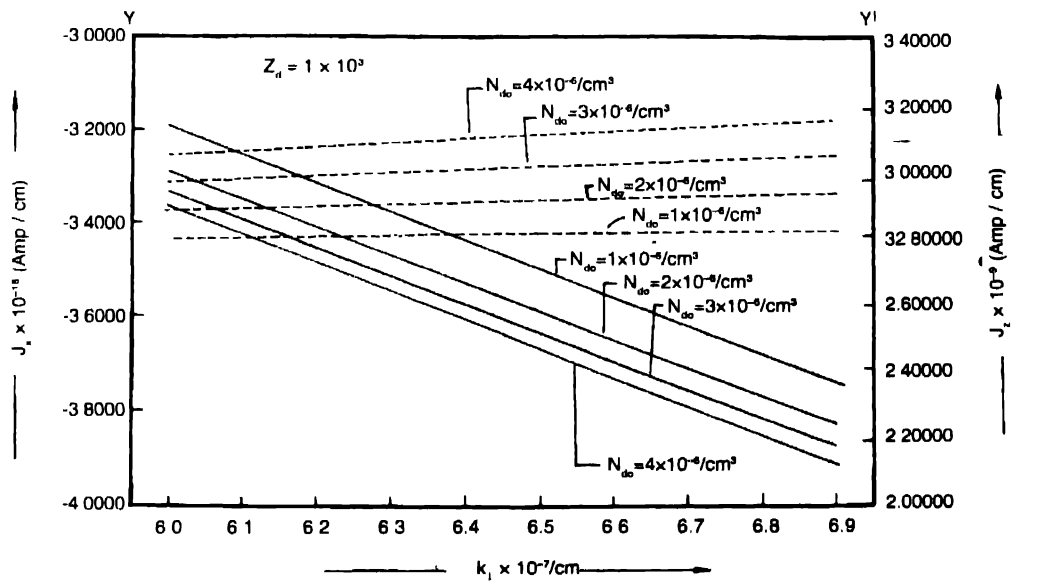

Figure 4. J_x (——) and J_z (-----) *versus* perpendicular wave number $k_\perp$ for different N_{d0}, $k_\parallel = 10^{-13}$ cm^{-1}

discussed ealier [6,7].We have not emphasized a particular auroral substorm event since most of the parameters are not available with us for the single event. The experimental observations of KAW pertaining to magnetosphere -ionosphere coupling regarding to the auroral acceleration process have already been indicated [6,7] and the present paper have dealt with the effect of dust grain on the kinetic Alfvén wave model.

Our present study may also help us to understand the filamentary structures existing within the diffuse aurora if the plasma is taken to be inhomogeneous . When the spectacular display of luminous radiation (auroras) in the arctic skies are examined carefully, some clear microscopic patterns, such as the discrete arcs having curtain shapes with spacing of a few tens of kilometers are observed. The earth's magnetosphere may be abundant with dust particles originating from collisional fragmentation of debris from comets, industrials contamination *etc* creating an environment for dusty plasmas. If the formation of kinetic Alfvén waves is possible in the earth's magnetosphere, then the acceleration of the electrons or protons by the kinetic Alfven wave along the line of force will convincingly explain the observed discrete arcs of filamentary structure of the aurora.

In this paper, we have investigated the occurrence of KAW in dusty plasmas dominated by the dust particle collective dynamics This theory may be useful to study the electrodynamics of auroral ionospheric region. The presence of field-aligned current in the auroral ionosphere, can permit short wavelength drift KAW to grow at lower altitudes. The KAW is a potential candidate for radio-frequency heating of a fusion plasma because low cost power sources in the appropriate frequency range are readily available and its absorption rate is high [2]. With the help of this study, one can explain the formation of the auroral arcs and the associated phenomena at the sub-storm times The field-aligned currents are the critical feature of magnetosphere - ionosphere coupling. The dust particles of the lower ionospheric region may modify the propagational features of kinetic Alfvén wave, associated currents and electric fields of the auroral regions as predicted in our findings.

The results of the present investigations should be useful in understanding the salient features of low-frequency fluctuations and associated nonlinear structures in planetary rings, in interstellar dust -molecular clouds, in supernova explosions, in cosmic particle acceleration, and in cometary plasmas where massive charged particulates are common.

Here, we have extended particle aspect approach to the analysis of kinetic Alfvén wave in magnetized dusty plasma . The associated perpendicular current and field-aligned current are calculated . The enhancement of wave frequency and growth rate of the kinetic Alfvén wave by negatively charged dust grain is predicted by this model . The density of dust grain has reduced the wave frequency and the growth rate of the wave. Both the parameters, the charge density and the number density, have affected the currents associated with the wave. Thus, the presence of dust particles in the auroral ionosphere and in the auroral acceleration region, may change the scenario of magnetosphere-ionosphere coupling model by the kinetic Alfvén waves. If the measurements of dust particles are made by the future satellites and space probes, the other wave phenomena also may be reconsidered to explain various observations in the magnetosphere.

Acknowledgment

One of us (RPS) is thankful to Department of Science & Technology, New Delhi and other (PV) to Indian Space Research Organisation, Bangalore for financial assistance .

References

[1] N Ya Kotsarenko, S V Koshevaya and A N Kotsarenko *Phys. Scripta* **56** 388 (1996)

[2] A C Das, A K Misra and K S Goswami *Phys Rev* **E53** 4 4051 (1996)

[3] P K Shukla and H U Rahman *Planet Space Sci.* **44** 469 (1996)

[4] R V Reddy, G S Lakhina, F Verheest and P Meuris *Planet Space. Sci* **44** 129 (1996)

[5] V S Tsypin, S V Vladimirov, A G Elfimov, M Tendler, A S de Assis and C A de Asevedo *Phys Plasmas* **4** 3436 (1997)

[6] A Baronia and M S Tiwari *Planet Space Sci* **47** 1111 (1999)

[7] A Baronia and M S Tiwari *J Plasma Phys* **63** 311 (2000)

[8] A K Dwivedi, P Varma and M S Tiwari *Planet Space Sci.* **49** 993 (2001)

[9] A K Dwivedi, P Varma and M S Tiwari *Planet Space Sci.* **50** 93 (2002)

[10] A Hasegawa *Proc. Indian Acad Sci* **86A** 151 (1977)